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# ANALYSIS OF CYGNUS ELECTRICAL SIGNALS*

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*Abstract*

The United States initiated the Subcritical Experiment (SCE) program to support a stockpile stewardship mission shortly after the 1992 moratorium on underground nuclear testing was established. Many SCE's are conducted at the Nevada National Security Site (NNSS) in Nevada. Cygnus is a high energy radiation generating device (RGD) located and operated at the NNSS and is a primary diagnostic for the SCE program.

The Cygnus Dual Beam Radiographic Facility consists of two identical radiographic sources, Cygnus 1 and Cygnus 2. From creation of the high power V-I drive to energy transport and X-ray conversion at the rod-pinch diode, the Cygnus machines utilize the following components: oil-filled Marx generator, water-filled pulse-forming line (PFL), water-filled coaxial transmission line (CTL), three-cell vacuum induction voltage adder (IVA), and rod-pinch diode. The diode pulse has the following electrical specifications: 2.25 MV, 60 kA, 60 ns. Each source has the following X-ray specifications: 1 mm diameter, 4 rad at 1 m, and 50 ns radiation pulse. SCE's are both single-event and high-value, therefore a high level of performance in reliability and reproducibility are key issues of Cygnus. Prior to executing such a SCE, there are a formidable number of shots (e.g. each of the two Cygnus RGD's charging and discharging properly into the rod-pinch diode load) that must be executed to determine reliability and reproducibility of the Cygnus RGD's. For every shot on Cygnus, voltages and currents along the machine are recorded and analyzed. In this paper we summarize attributes of the voltage and current waveforms at different locations using distribution plots. These distribution plots are used to quantify the reliability and reproducibility for Cygnus.

This analysis methodology will provide a standard to trouble shoot results of individual Cygnus shots, and also to monitor long term Cygnus performance. Accordingly, this type of extensive analysis will contribute to optimized Cygnus performance on SCEs.

## I.CYGNUS LAYOUT

The Cygnus layout is shown in Figure 1. The major components of Cygnus are Marx Generator, Pulse Forming Line (PFL), Coaxial Transmission Line (CTL), Inductive Voltage Adder (IVA), and Rod Pinch Diode.

Two Cygnus machines, Cygnus 1 and Cygnus 2, are independent to each other. Their X-ray beams cross each other at 60º. The components of Cygnus 2 are labeled.

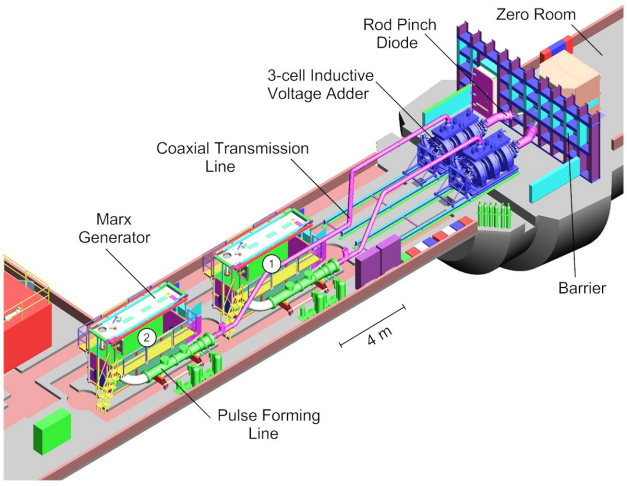


**Figure 1.** Cygnus layout.

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## II.CYGNUS SIGNALS

Along the machine, D-dot and B-dot probes are placed to monitor voltage and current. They are recorded and monitored for every shot. For this paper, we selected some typical signals along the machine: VPFL2, IPFL2, VPFL4, IPFL4, VTL2, ITL2, VSTK3 and IPLT.

Figure 2 shows the locations of signals along the Cygnus 1 machine.

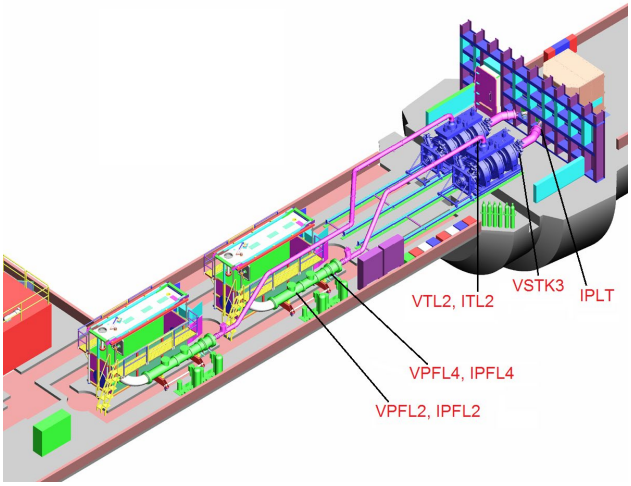


**Figure 2.** Cygnus signal locations.

## III.SIGNAL PLOTS

### *A. Pulse Forming Line (PFL) Signals*

VPFL2 and IPLF2 signals are located before the PFL switch. They are located 50 cm downstream from oil/ water barrier.

VPFL4 and IPLF4 signals are located about 160 cm downstream from VPFL2 and IPFL2.

VPFL2 and VPFL4 use one D-dot probe; while IPFL2 and IPFL4 use one B-dot probe.

Figures 3, 4, 5, 6 show the plots of VPFL2, IPFL2, VPFL4, and IPFL4 respectively.

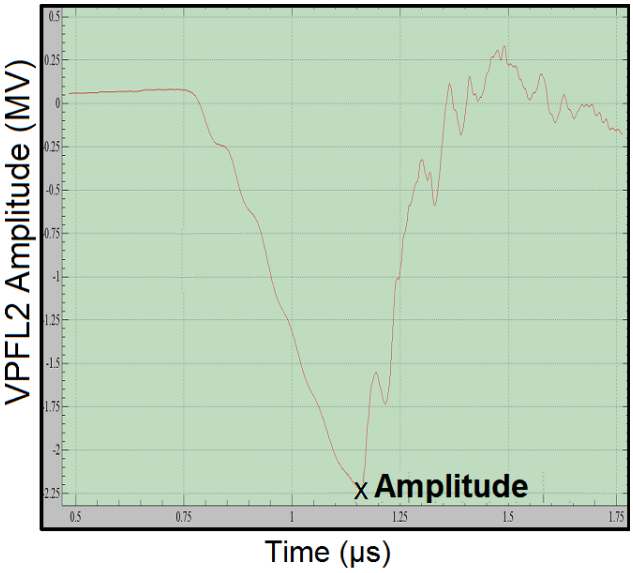


**Figure 3.** VPFL2 plot.

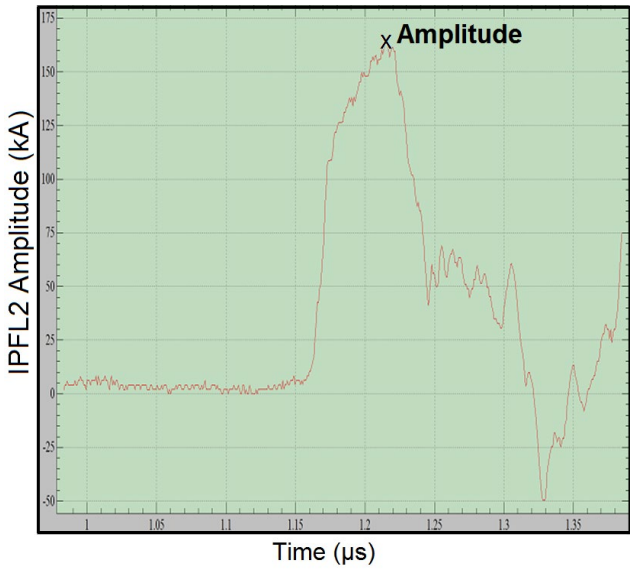


**Figure 4.** IPFL2 plot.

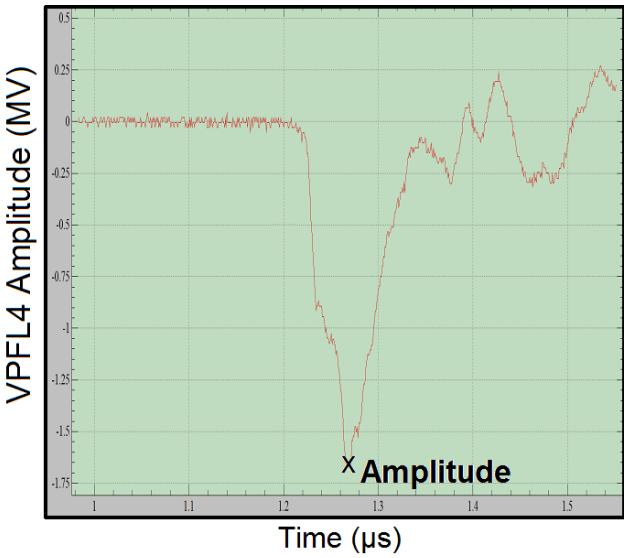


**Figure 5.** VPFL4 plot.

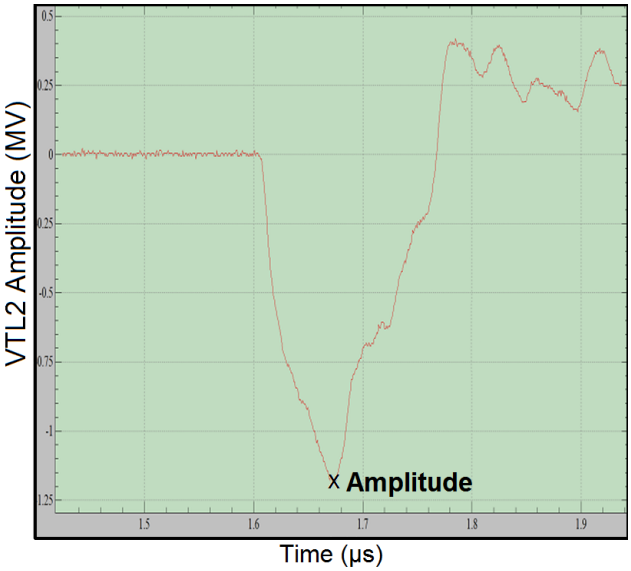


**Figure 7.** VTL2 plot.

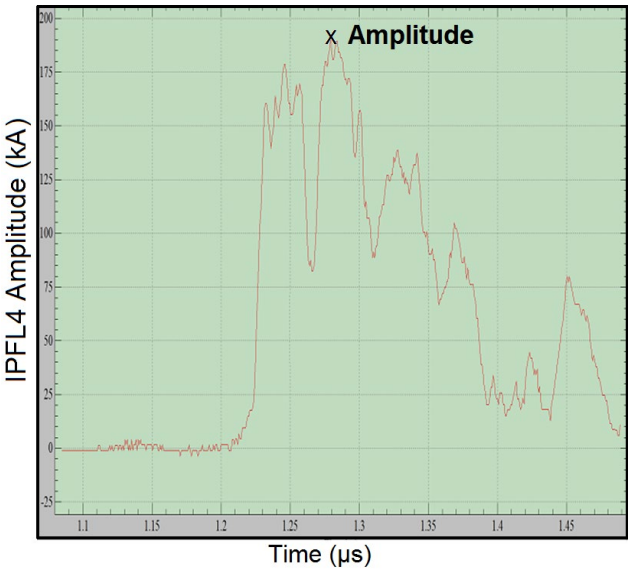


**Figure 6.** IPFL4 plot.

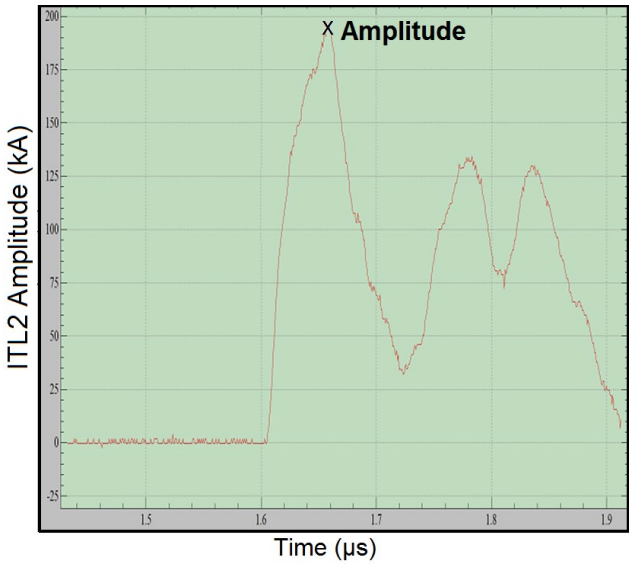


**Figure 8.** ITL2 plot.

### *B. Coaxial Transmission Line Signals*

Coaxial transmission line signals (VTL2 and ITL2) are located at the end of coaxial transmission line before the IVA.

VTL2 uses one D-dot probe; while ITL2 uses one B-dot probe.

Figures 7, 8 show the plots of VTL2 and ITL2 respectively.

### *C. Diode Signals*

Diode stalk voltage (VSTK3) uses two D-dot probes, with signals summed, integrated, and inductively corrected. VSTK3 is located in the stalk inside vacuum, at 115 cm upstream from the cathode plate.

Diode plate current (IPLT) uses three B-dot probes, with signals summed and integrated. IPLT is located in the diode end plate.

Figures 9 and 10 show the plots of VSTK3 and IPLT respectively.

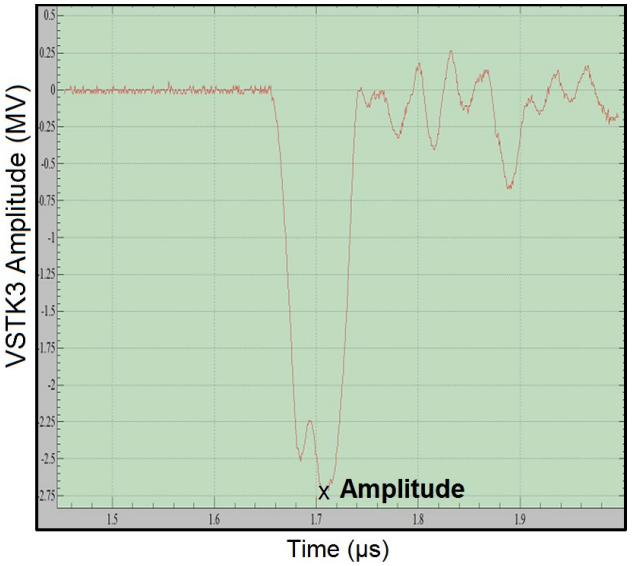


**Figure 9.** VSTK3 plot.

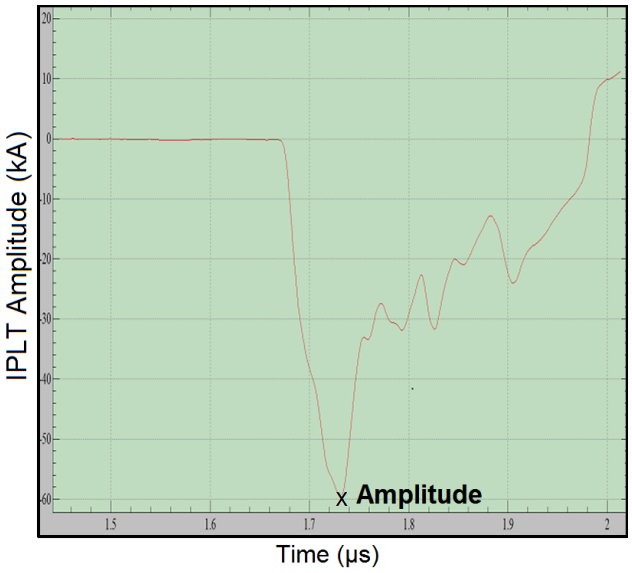


**Figure 10.** IPLT plot.

## IV.DATA ANALYSIS

For data analysis, we use 100 Cygnus 1 shots typically as calibration data. These shots include 98 normal dose shots (with dose from 3.73 Rad to 4.83 Rad) and two low dose shots (shot # 3814 with dose of 2.25 Rad; and shot # 3968 with dose of 2.60 Rad.) We developed a LabVIEW program to extract the amplitudes from shot data. Then we compiled distribution plots of amplitudes with average (µ) and 6σ windows (σ = standard deviation).

Figures 11, 12, 13, 14, 15, 16, 17, 18 show the distribution plots of VPFL2, IPFL2, VPFL4, IPFL4, VTL2, IPL2, VSTK3, and IPLT respectively. In these figures, the solid vertical hard lines are averages (µ) and the dashed vertical blue lines indicate 6σ.

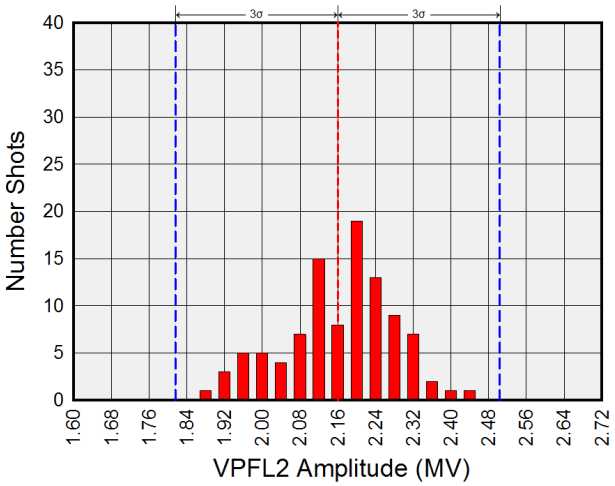


**Figure 11.** VPFL2 distribution plot.

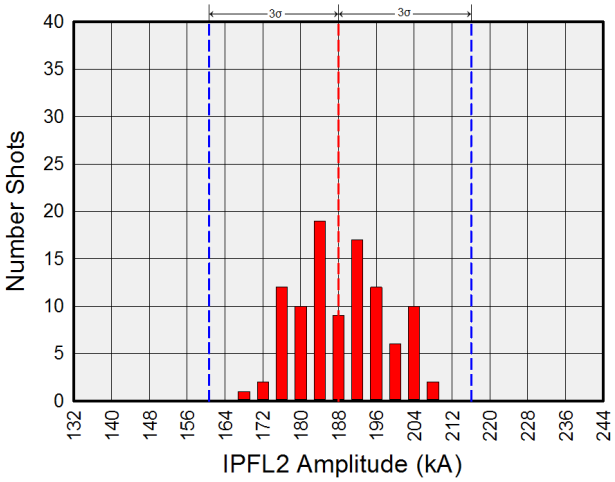


**Figure 12.** IPFL2 distribution plot.

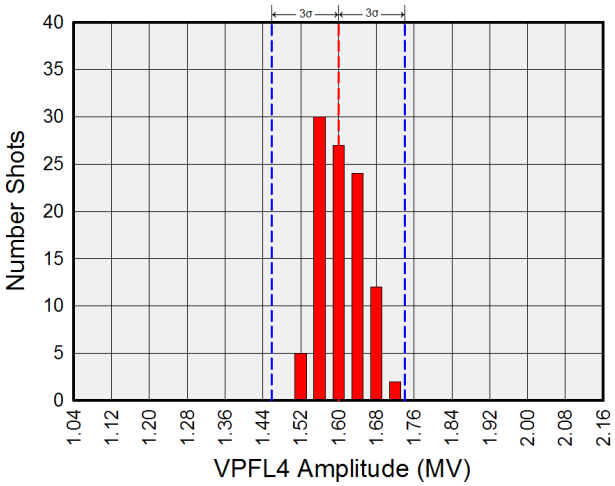


**Figure 13.** VPFL4 distribution plot.

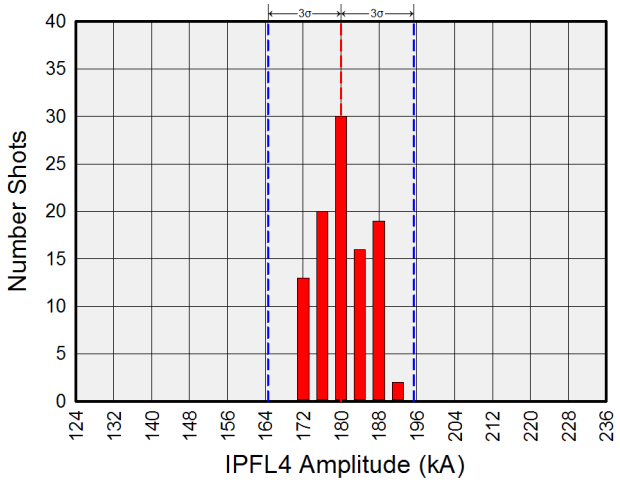


**Figure 14.** IPFL4 distribution plot.

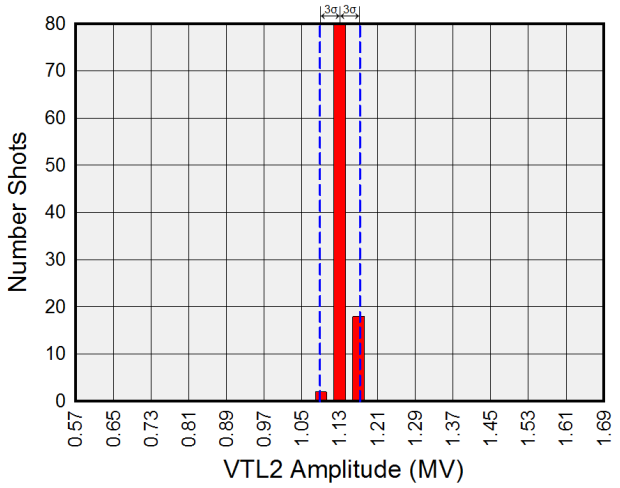


**Figure 15.** VLT2 distribution plot.

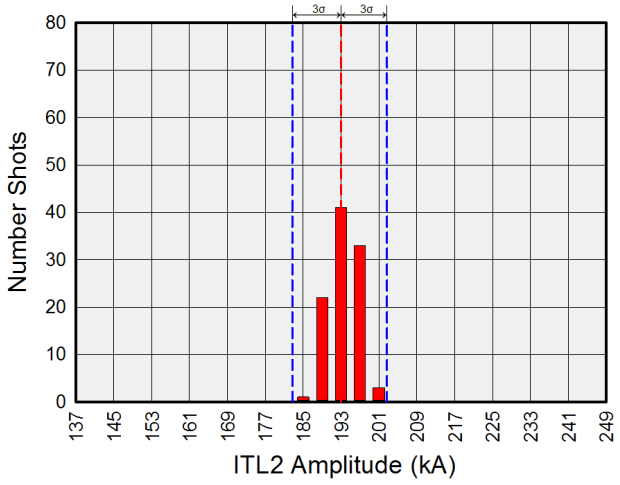


**Figure 16.** ILT2 distribution plot.

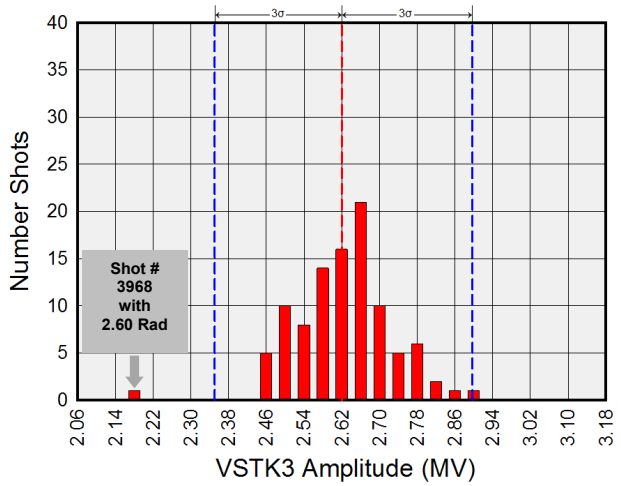


**Figure 17.** VSKT3 distribution plot.

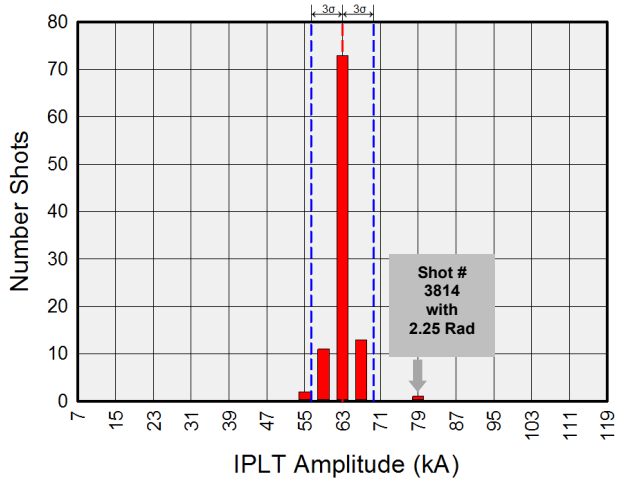


**Figure 18.** IPLT distribution plot.

| | μ | σ | % |
|---|---|---|---|
| **VPFL2 (MV)** | 2.16 | 0.11 | 5.3 |
| **VPFL4 (MV)** | 1.60 | 0.04 | 2.9 |
| **VTL2 (MV)** | 1.13 | 0.01 | 1.2 |
| **VSTK3 (MV)** | 2.62 | 0.09 | 3.5 |
| **IPFL2 (kA)** | 188 | 9.24 | 4.9 |
| **IPFL4 (kA)** | 180 | 5.14 | 2.9 |
| **ITL2 (kA)** | 193 | 3.33 | 1.7 |
| **IPLT (kA)** | 63 | 2.21 | 3.5 |

**Table 1.** Amplitudes Population Statistics.

As showed in table 1, all of the signals have standard deviation less than 5.3%.

## V.SUMMARY

Cygnus is a primary diagnostic for the SCE program. Since SCE's are both single-event and high-value, a high level of performance in reliability and reproducibility are key issues of Cygnus. Distribution plots are used to quantify the reliability and reproducibility for Cygnus. Any signal that falls out of the 6σ window will be carefully reviewed. In this set of data the VSTK3 of shot # 3968 and IPLT of shot # 3814 are out the their 6σ windows and corresponded to low dose shots.

## VI.REFERENCES

J. Smith et al., "Performance of the Cygnus x-ray source" in Proceedings of the 15th IEEE Pulsed Power Conf., 13-17 June 2005, pp. 334-337.

J. Smith et al., "Cygnus dual beam radiography source," in Proceedings of the 15th IEEE International Pulsed Power Conference, 2005, pp. 334-337.